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REVISED BIOLOGICAL PARAMETER ESTIMATES FOR APPLICATION IN YELLOWFIN STOCK ASSESSMENT

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Executive Summary

Previous western and central Pacific Ocean (WCPO) yellowfin stock assessments assume that the reproductive potential is proportion to the spawning stock biomass, with maturity at age the only explicitly reproduction-related factor taken into account. Recruitment to maturity for yellowfin is affected by a number of intrinsic factors, including size-related, age-related, and spatial changes in sex ratio, fecundity per kg, spawning fraction, and egg viability. We provide parameterisations of these factors for consideration in future yellowfin stock assessments. The analysis specifically examines assumptions that sex ratio is constant for all age classes and spatial locations, alternate fecundity and length relationship, and potential spatial variation in maturity at age in the WCPO.

We observed differences in the estimates of the maturity at length by longitude, with L_{50} for yellowfin sampled from Indonesia smaller than that observed elsewhere in the WCPO. Alternative growth curves influenced maturity at age estimates with the region 3 growth curve resulting in older maturing individuals than that observed when the standard WCPO wide growth curve was applied. This influence was also detected when calculating the maturity schedule for each of the alternative growth curves. Regional differences in sex ratio were detected, with the yellowfin sampled from region 3 more male biased at sizes above 130 cm than was observed in other regions. Natural mortality at age was influenced by the sex ratio data used and by the growth curve applied, with region 3 sex ratio and growth curve lowering the estimate of aggregate natural mortality for age classes between 2.5-5 yrs. Similarly region 3 sex ratio and growth curve influenced the estimate of male bias in comparison to the WCPO-wide parameterisation. Different relationships for fecundity at age and spawning fraction at age for the full model and for region 3 were also observed.

These alternative parameterisations of the intrinsic factors that describe reproductive potential for yellowfin in the WCPO indicate that more explicit modelling of these processes and variances may be warranted for future stock assessments of yellowfin. A sensitivity analysis to identify the influence that these alternatives have on the reference points used to assess yellowfin stock status is recommended as a first step. Similarly consideration of alternative or complementary explanations for the observed trend in sex ratio with size, other than increased natural mortality of mature females, is warranted. Models based on such alternative structural assumptions may result in different stock status estimates.

Introduction

Stock assessments of Pacific yellowfin tuna have been routinely undertaken for the western and central Pacific Ocean (WCPO), and eastern Pacific Ocean (EPO). In the WCPO, reference points from these assessments (e.g. $F_{current}/F_{MSY}$, $SB_{current}/SB_{MSY}$, etc) are used by the members of the Western and Central Pacific Fisheries Commission (WCPFC) for evaluating the status of stocks. Recent stock assessments for yellowfin tuna indicate an increased probability that these reference points are being approached or exceeded, to the extent that conservation measures may need to be considered to ensure long term sustainable of the fishery (Langley *et al.* 2007).

Stock assessments use models of the population dynamics of a species to estimate these reference points. As these models are simplifications of reality they are influenced by structural uncertainties (i.e. the choice of parameters used to describe biological processes, and the methods and assumptions used to combine these parameters together), and parameter uncertainties (the availability, precision and accuracy of information used to estimate each of these parameters). Consequently, understanding the influences of these uncertainties on the outputs of models is an important aspect of considering the actions to implement from a stock assessment.

The reproductive potential (RP) of the stock is the ‘stock’ component of the stock recruitment relationship (SRR). The SRR is the way that density-dependence is introduced into the model, and it is partly as a consequence of this that RP is an important reference point (e.g. $SB_{current}/SB_{MSY}$). The RP also acts as an indicator of the amount of reproductive potential needed for the stock to be sustainable – some management regimes prescribe 20% of unfished RP as a limit reference point (Mace and Sissenwine 1993).

Many stock assessments represent RP by spawning stock biomass (SSB), which assumes that a population’s RP is proportional to its SSB (Trippel *et al.* 1997). This is the approach taken by previous WCPO yellowfin stock assessments (Hampton *et al.* 2006, e.g. Langley *et al.* 2007). However, the only explicitly reproduction-related factor taken into account with SSB is maturity at age (defined in the current yellowfin stock assessment at age 6 months). Recruitment to age 6 months for yellowfin is affected by a number of factors, and including more of them explicitly in the stock assessment model will improve the predictive power of the model. These factors can be divided into those that are intrinsic to RP, and external factors such as environmental effects and random variation. Factors intrinsic to RP include size-related, age-related, and spatial changes in sex ratio, fecundity per kg, spawning fraction, and egg viability. Environmentally-driven variation includes short-term temporal variation in the proportion of the population mature at a particular age, fecundity, and egg quality.

The approach used here to estimate natural mortality at age has been previously applied to bigeye (Harley and Maunder 2003, Watters and Maunder 2001) and yellowfin (Maunder and Watters 2001) tunas in the EPO, and to albacore (Hoyle 2008) and bigeye (Hoyle and Nicol 2008) tunas in the WCPO. Previous WCPO yellowfin assessments have applied a natural mortality ogive calculated using EPO data (Maunder and Watters 2001). Previous work developing RP ogives for WCPO tunas has been carried out for albacore (Hoyle 2008) and bigeye (Hoyle and Nicol 2008) tunas in the WCPO.

In this paper we recalculate the RP in terms of the factors most likely to affect true reproductive output for use in the 2009 yellowfin stock assessment. The analysis specifically examines:

(1) The structural assumption that both sexes contribute to reproductive potential.

> In previous yellowfin assessment, sex ratio has been assumed to be constant for all age classes. In yellowfin tuna (Schaefer 1998) and many other tuna species, the proportion of females in the catch declines with age and size. This phenomenon is observed in both purse seine and longline

data (IATTC unpublished data). This “trend in sex ratio” is assumed to reflect a trend in the population sex ratio, and to be driven by differential natural mortality at age between the sexes, associated with the stress of reproduction (Schaefer 1998). We model this trend in sex ratio at age to examine whether spatial influences are present and to evaluate the influence of different paramterisations on the calculation of natural mortality at age and sex ratio at age estimates.

(2) The structural assumption that spawning biomass is an indicator of reproductive potential.

In previous yellowfin assessments, spawning biomass is used as an indicator of reproductive output. This assumes that the fecundity (combined with spawning fraction) is directly proportional to weight at age. However, an alternative estimate of RP could be applied using egg production, which may increase more rapidly than biomass with length. For WCPO yellowfin tuna the exponent of the length-weight relationship is 2.94, while the exponent of the length-fecundity relationship is 3.27 (Itano 2000), indicating that large fish dedicate considerably more of their biomass to egg production. We include the observed relationship of fecundity with length.

In the standard yellowfin assessment, spawning fraction is assumed to be uniform for all females. This assumption has not been examined for yellowfin in the WCPO, but in the EPO the spawning fraction was found to increase with length (Schaefer 1998). We recalculate the WCPO yellowfin RP using egg production by applying the EPO spawning fraction at length relationship.

(3) The influence of parameter uncertainty for yellowfin maturity schedule.

The age schedule of yellowfin RP depends on the growth curve and data on yellowfin maturity, fecundity, spawning fraction, and sex ratio at length. Spatial variation in growth rate has been hypothesised for yellowfin tuna in the WCPO (Langley *et al.* 2007). Maturity at length differs between the EPO (Schaefer 1998) and WCPO, and within the WCPO (Itano 2000). Patterns of fecundity at length may vary between the WCPO (Itano 2000) and EPO (Schaefer 1998), and possibly within both regions. There is no published information on spatial variation in spawning fraction at length. Sex ratio at length appears to vary significantly in space within the WCPO (SPC unpublished data) and EPO (Everett and Punsly 1994). The available information to calculate spatial variation in RP throughout the WCPO is quite limited. We carry out preliminary analyses, to evaluate the extent of potential variation in maturity at age in the WCPO.

Methods

Preparation of input values

1. Growth curves

In MFCL, the distribution of length at age is determined by the growth curve

(Eqn 0.1)
$$L_a = L_1 + \left(L_A - L_1\right)\left[\frac{1-e^{-K(a-1)}}{1-e^{-K(A-1)}}\right]$$

where L_1 is the mean length at the first age, L_A is the mean length of the oldest age, and K is the von Bertalanffy growth coefficient (Kleiber *et al.* 2006), and standard deviation of length at age:

(Eqn 0.2)
$$sd.length_a = sda \cdot e^{-sdb.\left(1-2\frac{L_a-L_1}{L_{max}-L_1}\right)}.$$

In the most recent assessment (Langley *et al.* 2007) it was observed that growth estimated from the entire WCPO model yields substantially higher growth rate for age classes 2–7 compared with growth estimates for Region 3 only (Figure 1, Table 1). Growth estimated from the WCPO model was more consistent with size frequency data from fisheries targeting large fish, particularly outside region 3, and with otolith length-increment data that came largely from outside region 3 (Lehodey and Leroy 1999). Growth estimated from the Region 3 model was in most cases consistent with size data from the LL fishery in the Bismarck sea and from fisheries that catch predominantly small fish, with growth increments derived from tag data, and with otolith increment data from the Indonesia-Philippines (IDPH) region (Yamanaka 1990).

Growth in region 3 was therefore modeled with the growth curve from the region 3 model, while growth for other regions was modeled with the growth curve estimated from the whole-WCPO model.

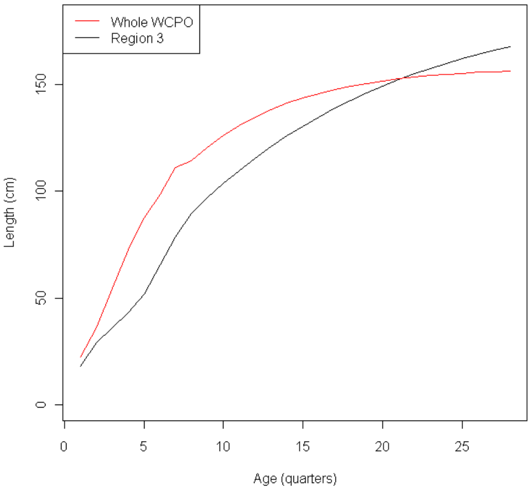


Figure 1: Growth curves

Table 1: Parameters of the two growth curves

	WCPO wide 2007	Region 3, 2007
L_A	156.40	167.85
K	0.15818	0.073744
L_1	25.118	21.131
sda	9.4568	6.96073
sdb	0.65808	0.43328
Age_pars	-3.0390	-2.4863
	-4.1437	-8.5385
	-8.4050	-6.5945
	-11.6171	-2.6855
	-12.6023	0.2303
	-8.0269	0.7844
	-3.2325	4.4349

2. Maturity schedules

Maturity schedules were calculated for the IDPH region, the WCPO excluding the IDPH, and under the assumption that growth rate did not vary spatially (ie a WCPO wide estimate). Information on maturity is available at length (Itano 2000), but Multifan-CL requires a schedule of maturity at age. We used the data from Itano (2000) to estimate the distribution of maturity at length, using the model

$$mat_{len} = \left(1-(1-m)\cdot e^{-\kappa(len-x)}\right)^{\frac{1}{1-m}}.$$

Proportion mature at length for IDPH fish was estimated, $L_{50} = 93.86$, where $m = 1.69$, $\kappa = 0.0855$, and $x = 92.6$. For WCPO region outside the IDPH, $L_{50}=109.8$, where $m = 4.51$ $\kappa = 0.369$, and $x = 112.8$. When all data were combined (WCPO wide estimate), $L_{50}=106$, where $m = 3.7$, $\kappa = 0.244$, and $x = 108.9$.

For a given age, $p(mat) = \sum_{len} p(len)\cdot p(mat \mid len)$. We then used the appropriate growth curve to convert each estimate to maturity at age.

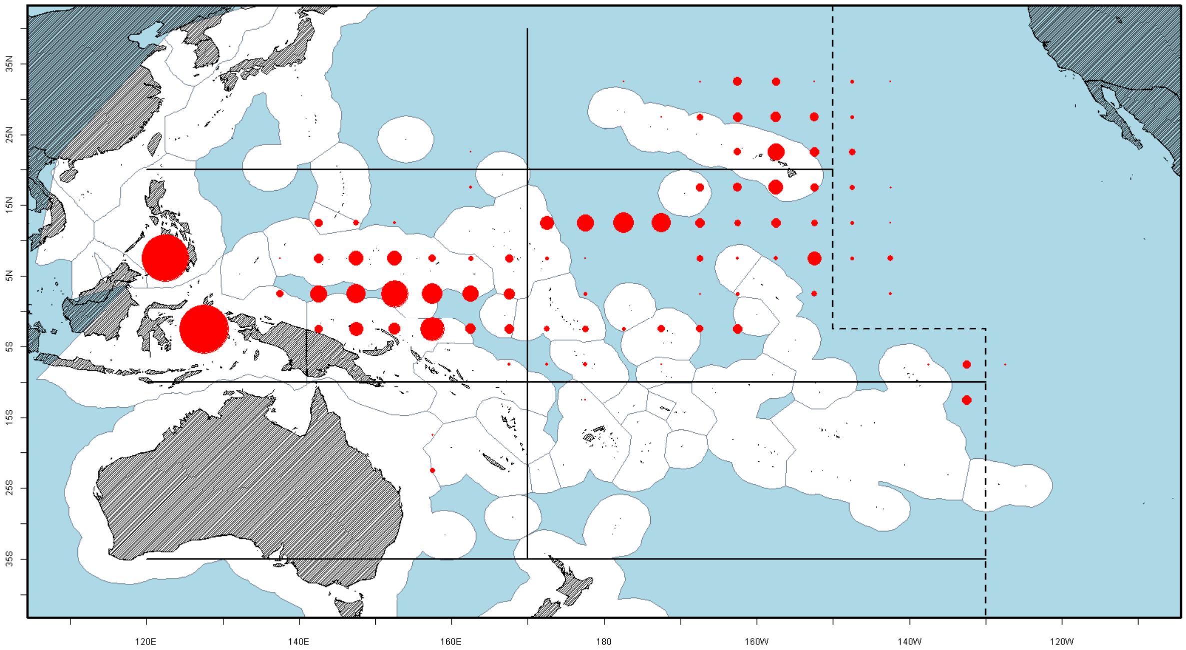


Figure 2: Maturity samples by location

3. Sex ratio at length and natural mortality at length

SPC observer data were examined to determine yellowfin sex ratio at length in longline catches from the Pacific. Data were restricted to fish between 100 and 170 cm. A total of 24,222 sexed yellowfin were in the dataset.

Differential natural mortality at age between the sexes was modelled by estimating the natural mortality parameters that gave the best fit to the sex ratio data. Following Harley and Maunder (2003), natural mortality M was modelled in three phases: (1) mortality the same for males and females, and declining from M^0 at the initial age (min age) at a rate of δ per time step to some breakpoint; (2) mortality M^1 constant and the same for males and females until females begin to mature; (3) constant mortality for males but higher mortality for mature females M^2 than for immature females. There may be a lag l between maturity and increasing mortality.

Natural mortality for males was:

(Eqn 0.3)
$$M_{M,a} = \begin{cases} M^0 & \text{for } a = a_{min} \\ M_{M,a-1} - \delta & \text{for } a = a_{\min} + 1, \ldots, a_{break} \\ M^1 & \text{for } a_{break} + 1, \ldots a_{max} \end{cases}$$

$$\delta = \left(\frac{M^1 - M^0}{a_{break} - a_{min}} \right)$$

For females, the full mortality schedule, given proportion mature φ_a, was:

(Eqn 0.4)
$$M_{F,a} = \begin{cases} M^0 & \text{for } a = a_{min} \\ M_{F,a-1} - \delta & \text{for } a = a_{min}, \ldots, a_{break} \\ M^1 \left(1 - \varphi_{a-l}\right) + M^2 \left(\varphi_{a-l}\right) & \text{for } a = a_{break} + 1, \ldots, a_{max} \end{cases}$$

Length at age, based on a growth curve, was used to convert sex ratio at length into sex ratio at age. The two alternative growth curves used were: the WCPO wide and the region 3 growth curve from the 2007 stock assessment (Langley *et al.* 2007). Length at age was modelled as in Equation 0.1. The standard deviation of length at age is calculated as in Equation 0.2. Parameter values are given in Table 1.

Given the assumed length at age and standard deviation of length at age, the proportion of fish age *a* in length class *len*, $p_{a,len}$, was calculated, using 1 cm length intervals. Expected sex ratios at length by sex were calculated as

(Eqn 0.5) $$N_{sex,a} = N_{sex,a-1} e^{-M_{sex,a-1}}$$

(Eqn 0.6) $$N_{sex,len} = \sum_{a} N_{sex,a} \cdot p_{a,len}$$

The parameters M^2 and lag *l* were estimated by optimising the fit of the expected to the observed sex ratio, using the χ^2 distribution.

Since natural mortality and predicted sex ratio are affected by the maturity schedule and growth rate, natural mortality and sex ratio were re-estimated for each maturity schedule and growth rate examined in the sensitivity analysis.

4. Fecundity at length

In previous assessment fecundity is assumed to be proportional to weight. In this analysis we recalculate the fecundity at length relationship for the WCPO wide and region 3 using the yellowfin length-fecundity relationship estimated by Itano (2000), $fecundity = a \cdot length^{b}$, with $a = 2.934 \times 10^{-5}$ and $b = 3.2673$.

5. Spawning fraction

In previous assessment the spawning fraction for all age classes was assumed to be equal. In this analysis we applied the yellowfin spawning fraction at length relationship, which is from the EPO (Schaefer 1998) to the length data for region 3 and the WCPO wide. The equation is

$fraction_{length} = y_{\infty}\left(1 - e^{-y_k.(length - y_0)}\right)$, with $y_{\infty} = 0.742$, $y_k = 0.046$, and $y_0 = 54.892$.

Results

1. Maturity schedules

We observed differences in the estimates of the maturity at length by longitude, with L_{50} for yellowfin sampled from Indonesia smaller than that observed elsewhere in the WCPO (Figure 3). We did not detect differences in L_{50} by latitude (i.e. no observable difference in the L_{50} estimates between yellowfin sampled in the Philippines, Hawaii, region 3 and region 4; Figure 3). Alternative growth curves influenced maturity at age estimates with the region 3 growth curve resulting in older maturing individuals than that observed when the standard WCPO wide growth curve is applied (Figure 4). This influence was also detected when calculating the schedule of reproductive potential for each of the alternative growth curves (Figure 5).

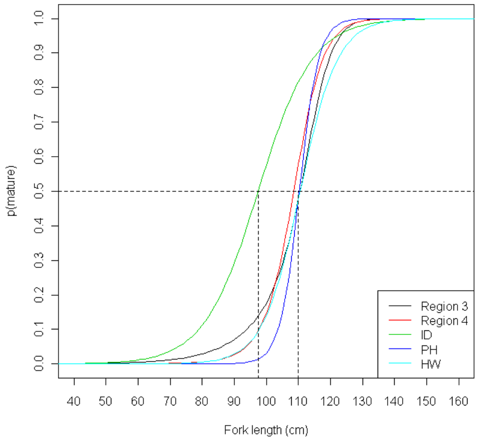


Figure 3: Maturity at length by location

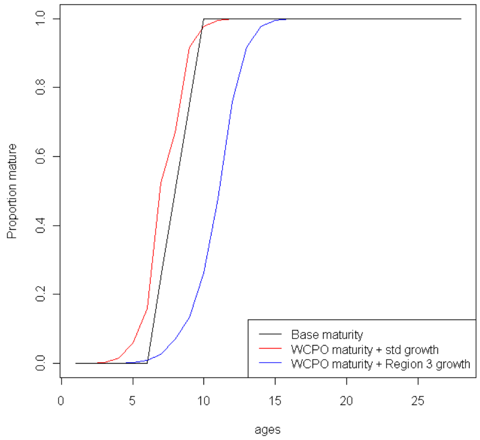


Figure 4: Maturity at age estimates from the estimated WCPO maturity-at-length and alternative growth curves

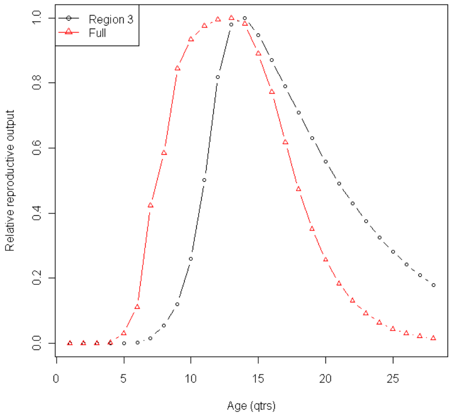


Figure 5: Schedule of reproductive potential

2. Inclusion of sex ratio in the calculations of reproductive parameters and natural mortality at length

Regional differences in sex ratio were detected, with the yellowfin sampled from region 3 more male biased at sizes above 130 cm than was observed in other regions (Figure 6). Natural mortality at age was influenced by the sex ratio used and the growth curve applied (Figure 7) with region 3 sex ratio and growth curve lowering the estimate of aggregate natural mortality for age classes between 10 and 20 quarters (2.5-5 yrs). Similarly region 3 sex ratio and growth curve influenced the estimate of male bias in comparison to the WCPO wide parameterisation (Figure 8).

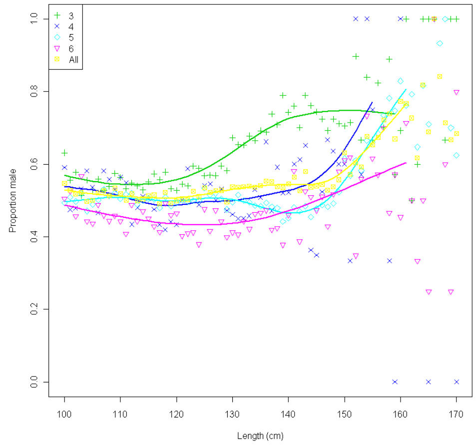
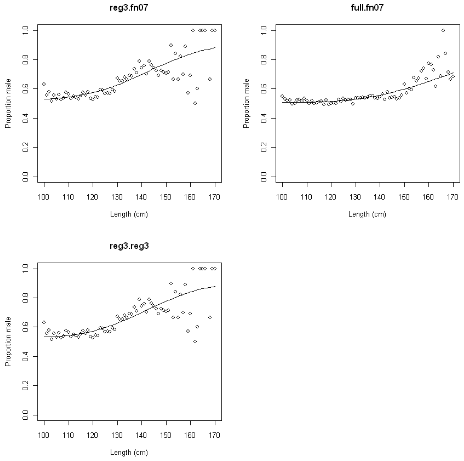


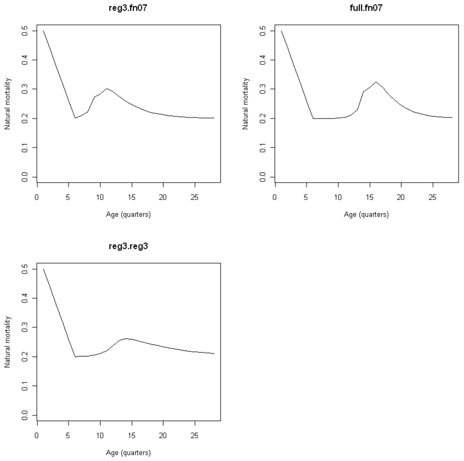
Figure 6: Sex ratio by region


reg3.fn07

full.fn07

reg3.reg3

Figure 8: Fit to sex ratio at age data for: (reg3.fn07) region 3 sex ratio with base case 2007 growth; (full.fn07)WCPO sex ration with base case 2007 growth; and (reg3.reg3)) region 3 sex ratio with region 3 growth.


reg3.fn07

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reg3.reg3

Figure 7: Natural mortality at age for: (reg3.fn07) region 3 sex ratio with base case 2007 growth; (full.fn07)WCPO sex ration with base case 2007 growth; and (reg3.reg3)) region 3 sex ration with region 3 growth.

3. Including fecundity and spawning fraction at length structure

The observed fecundity at length and spawning fraction at length ogives were combined with the appropriate regional growth curve to estimate fecundity at age and spawning fraction at age for the full model and for region 3 (Figure 9 and Figure 10).

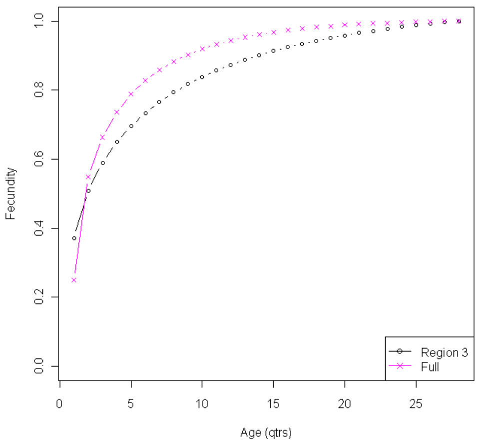

Figure 9: Relative fecundity

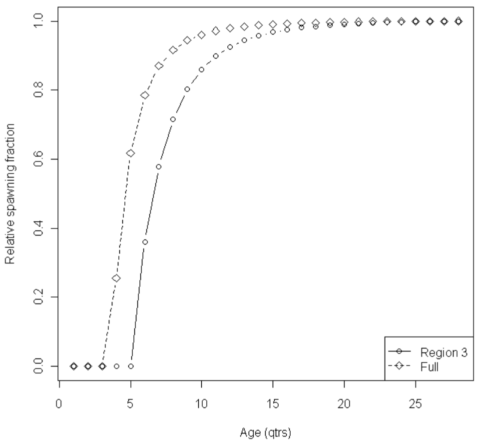

Figure 10: Relative spawning fraction

Discussion

We observed support for alternative parameterisations of the intrinsic factors that describe reproductive potential for yellowfin in the WCPO indicating that more explicitly modelling of these processes and variances may be warranted for future stock assessments of yellowfin. There was evidence to support that reproductive dynamics of yellowfin in region 3 are different to that observed elsewhere in the WCPO. In particular the alternative growth curve for region 3 appears to have strong influences upon the parameters that generate reproductive potential and natural mortality. The age data for yellowfin in the WCPO is limited and further analysis to validate the growth curve and its influence is warranted. The estimated sex ratio and maturity schedule for region 3 also differed. A sensitivity analysis would identify the influence that these alternatives have on the reference points used to assess yellowfin stock status.

In this study we have assumed that the observed trend in sex ratio with size is due to increased natural mortality of mature females. However, alternative or complementary explanations are possible, such as slower female growth (as seen in southern bluefin tuna (Farley *et al.* 2007), or lower catchability of mature or spawning females. Models based on such alternative structural assumptions may result in different stock status estimates. This is an important area for future research.

When the relationship between fecundity and length is included in the model, the relative contribution of older females increases. We note that the exponent of the length-fecundity relationship may be higher than 3.26, indicating higher reproductive contribution of older females. The fecundity dataset is aggregated across areas with different size distributions and different maturity at length, and potentially different fecundity at length. Analyses that aggregate non-homogeneous data are likely to be biased. The higher-density areas of region 3 have smaller females (SPC unpublished data) and higher rates of maturity at length (Itano 2000). If fecundity at length in these areas is also higher, then the rate of increase in fecundity at length is likely to be underestimated.

References

1. Everett, Ed and Punsly, Richard. (1994). Sex ratios of yellowfin tuna in the eastern Pacific Ocean: a new method for old data.

2. Farley, J. H., Davis, T. L. O., Gunn, J. S., Clear, N. P., and Preece, A. L. (2007). Demographic patterns of southern bluefin tuna, Thunnus maccoyii, as inferred from direct age data. *Fisheries Research* **83**, 151-161.

3. Hampton, J., Langley, A., and Kleiber, P. (2006). Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options. WCPFC SC2 SA WP-1, Manila.

4. Harley, Shelton and Maunder, Mark N. (2003). A simple model for age-structured natural mortality based on changes in sex ratios. IATTC, 4th Meeting of the Scientific Working Group, La Jolla, USA, May 19-21 2003.

5. Hoyle, S. D. and Nicol, S. (2008). Sensitivity of bigeye stock assessment to alternative biological and reproductive assumptions. No. WCPFC-SC4-2008/ ME-WP-1 (Secretariat of the Pacific Community: Nouméa, New Caledonia.)

6. Hoyle, S. D. (2008). Adjusted biological parameters and spawning biomass calculations for south Pacific albacore tuna, and their implications for stock assessments. No. WCPFC SC4/ME-WP-2 (Secretariat of the Pacific Community: Nouméa, New Caledonia.)

7. Itano, D. G. (2000). 'The Reproductive Biology of Yellowfin Tuna (Thunnus Albacares) in Hawaiian Waters and the Western Tropical Pacific Ocean: Project Summary.' (University of Hawaii, Joint Institute for Marine and Atmospheric Research.)

8. Kleiber, P., Hampton, J., and Fournier, D. A. (2006). MULTIFAN-CL User's Guide.

9. Langley, A. D., Hampton, J., Kleiber, P. M., and Hoyle, S. D. (2007). Stock assessment of yellowfin tuna in the western and central Pacific Ocean, including an analysis of management options. No. WCPFC-SC3, SA WP-1 (Secretariat of the Pacific Community: Noumea, New Caledonia.)

10. Lehodey, P. and Leroy, B. (1999). Age and growth of yellowfin tuna (Thunnus albacares) from the western and central Pacific Ocean as indicated by daily growth increments and tagging data. *WP YFT-2, SCTB* **12**, 16-23.

11. Mace, P. M. and Sissenwine, M. P. (1993). How much spawning per recruit is enough? In 'Risk Evaluation and Biological Reference Points for Fisheries Management'. (Eds S. J. Smith, J. J. Hunt, and D. Rivard.) pp. 101-118.).

12. Maunder, Mark N. (2007). Status of yellowfin tuna in the eastern Pacific Ocean. Document SAR-8-08a. Working Group to Review Stock Assessments , -75. La Jolla, California (USA), Inter-American Tropical Tuna Commission.

13. Maunder, M. N. and Watters, G. M. (2001). Condicion del atun aleta amarilla en el Oceano Pacifico oriental. Status of yellowfin tuna in the eastern Pacific Ocean. *Inter American Tropical Tuna Commission Stock Assessment Report* **1**, 5-86.

14. Schaefer, K. M.(1998). Reproductive biology of yellowfin tuna (Thunnus albacares) in the eastern Pacific Ocean. *Bulletin. Inter-American Tropical Tuna Commission/ Boletin. [Bull. IATTC/Bol. CIAT]. Vol. 21*, no.

15. Trippel, E. A., Kjesbu, O. S., and Solemdal, P. (1997). Effects of adult age and size structure on reproductive output in marine fishes. *FISH AND FISHERIES SERIES* **21**, 31-62.

16. Watters, G. M. and Maunder, M. N. (2001). Condicion del atun patudo en el Oceano Pacifico oriental. Status of bigeye tuna in the eastern Pacific Ocean. *Inter American Tropical Tuna Commission Stock Assessment Report* **1**, 109-210.

17. Yamanaka, K. L. (1990). Age, growth and spawning of yellowfin tuna in the southern Philippines.)